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The use of canonical analysis and factor analysis for identification of successional trajectories on disaster area in the Tatra Mts, Slovakia

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Abstract: In the present work, the authors provide the results of a nine-year monitoring of the post wind disturbance development in the Tatra Mts in 2004-2013. The authors observed dependency of dominant species *Calamagrostis villosa* and *Chamaerion angustifolium* on site management and detected the successional trajectories. In order to achieve the objectives, the authors used factor analysis and canonical analysis. Canonical "R" value is a trajectory indicator. *Calamagrostis villosa* recorded maximum development in a favourable light conditions on the EXT (windthrow removed) or NEX (windthrow left) sites in 2008-2011. Due to the overproduction of *Calamagrostis villosa*, reduced seed germination caused retreat of the plant cover. *Chamaerion angustifolium* recorded the maximum development in the charred sites rich in nitrogen (FIR), in 2007-2008. In the further development, the falling stocks of nitrogen supply caused the *Chamaerion angustifolium* abundance decline.

Keywords: Canonical analysis, factor analysis, forest disturbance, permanent quadrats, succession, High Tatra Mountains, Slovakia.

Introduction

In the nature-scientific disciplines, the factor analysis is rarely used. Factor analysis is similar to principal component analysis. While by the principal component analysis the principal components arise from variables, in the factor analysis, it is reversed, the variables result by the conversion of the factors. Factor analysis tries to understand the correlation structure. Canonical analysis solve the relationship between groups of variables, canonical variables do not explain the variance, but maximize the correlation.

The Tatra Mountains are located at the Northern, highest area of the Carpathian mountain range (Central Europe), along the Polish-Slovakian border. On November 19, 2004, the Northern down-slope wind (locally named Tatra Bora) felled 12,000 ha of forest, about 2,3 million m^3 of wood in the Tatra Mts. Consequently, at July 31, 2005 a large fire hit the windfall area and 250 ha was completely burnt.

Succession is the natural replacement of plant or animal species, or species associations, in an area over time. Each stage of succession creates the conditions for the next stage. Temporary plant communities are replaced by more stable communities until a sort of equilibrium is reached between the plants and the environment (MARTIN & GOWER 1996).

Succession results from processes of disturbance, differential availability of species to a site, differential performance of species within a site. Succession is driven by the interractions of organisms with each other and the physical environment. The species composition of a site tends to equilibrate with the environment of the site (PICKETT et al. 2011). Succession may persist for a very long time, even the period of 750 years after a stand-initiating disturbance was registered (FRANKLIN & SPIES 1991). Post-disturbance development of forest ecosystems in general is well known. FAJMONOVÁ (1975) gave a phytocoenological knowledge on clearing communities in flysch zone in the Westcarpathians. KRIŽOVÁ (1994) studied the dynamics of herbal coenoses after clear felling in fir-beech forests in Natural Reserve Mláčik in Kremnické vrchy Hills. UJHÁZY (2003) investigated secondary vegetation succession on abandoned secondary grassy vegetation on Poľana. The investigators have focused on post-fire or post disturbance investigation of vegetation generally long after disturbance events, decades or even centuries. An exception is the paper of MILLER & HALPERN (1988), who studied understory succession shortly after logging in the western Cascade Range of Oregon or JANE & GREEN (1986), who evaluated early succession after wind damage in New Zealand. In Slovakia, examples of studies of vegetation succession after forest fires is the investigation of NOVOTNÝ (1998) in the Záhorská nižina lowland, or in the Slovak Paradise National Park BEVILAQUA (2000), LESKOVJANSKÁ (1995), HOLECY et al. (2004), JANČOVÁ (1993; 2006).

Only limited number of studies dealing with after-fire succession are known to use ordination methods. FELDMEYER-CHRISTE et al. (2011) used principal coordinates analysis (PCOA) as ordination method, they monitored temporal stages over a 21-year period (1988 to 2008) in Swiss mire where a slide occured in 1987. REES & JUDAY (2002) compared logged sites and fire sites in overall plant species richness. All sites and species variables were compared using Two-way analysis of variance (ANOVA). Burning appears to eliminate more of the pre-existing community and return the site to an earlier successional condition than logging.

A long-term study on the vegetation successional dynamics of the disturbed area in the Tatra Mts was launched immediately after the event, in 2005. The very early succession have been investigated by more researchers, e. g. HOMOLOVÁ et al. (2009), OLŠAVSKÁ et al. (2008), ŠOLTÉS et al. (2007a,b; 2008; 2010), CHOVANCOVÁ-OLŠAVSKÁ & KRIŽOVÁ (2009), BUDZÁKOVÁ et al. (2013). The results of the mentioned researchers can be summarized as follows: Heavily burnt areas were colonized by plants disseminated by airborn diasporas, mainly by *Chamaerion angustifolium*, unburnt localities were settled by plants germinating from the soil seed bank or by plants surviving by root system (*Dyopteris carthusiana* agg., *Vaccinium myrtillus, Avenella flexuosa* and *Calamagrostis villosa)*. The felled-area species were recorded in each plot. The moss layer disappeared soon after the disturbance events. HOMOLOVÁ et al. (2011) confirmed colonization of heavily burnt areas by plants disseminated by air diaspores, and occupation less burnt by plants germinating from soil seed bank. KRIŽOVÁ et al*.* (2011) studied primary production of biomas in herb layer on calamity areas in Tatra Mts. The highest proportion of biomass production of *Vaccinium myrtillus* (average 82%), was recorded on the REF (reference) and NEX (windthrow left) plots, where *Calamagrostis villosa* had a lower proportion (average 15%). The expansive spread of *Chamaerion angustifolium* was observed on the plots FIR (burnt plots) and EXT (windthrow removed plots) since 2007. In 2009, on the plot FIR, *Ch*. *angustifolium* had the highest share on total biomass volume (49-74%), on the EXT plots (62%). On the REF area, the *Vaccinium myrtillus* maintained the highest proportion (94%) on the biomass volume. On NEX area, with high production and competitive ability, appeared *Calamagrostis villosa* (68%) to be dominant, and there were recorded the highest values of total biomass in both years (1536-10332 $kg.ha^{-1}$) as well. The observed values of total biomass was several times higher in the year 2009, than in year 2005, on the REF area (665-2215 $kg.ha^{-1}$) as well. A link with hydroregime of soils was demonstrated. The important factors are the competitive relationships in the process of succession, conditional on the emergence of vacant niche on particular areas FIR and EXT.

The following aims are addressed in this paper:

- To assess the suitability of canonical analysis and factor analysis for identification of succession trajectories
- To determine the preference of the dominant species in relation to the sites management
- To detect the successional trajectories

Material and methods

Nomenclature

The nomenclature of bryophytes follows KUBINSKÁ & JANOVICOVÁ (1998) and MARHOLD (1998) for vascular plants.

Sampling

The investigation is restricted to understory vegetation, since the canopy was completely removed by windthrow or by fire. Permanent plots were established under four different disturbance and management treatments: Reference plot (REF), windthrow removed (EXT), burnt plot (FIR), windthrow left (NEX). The plots were established and analysed in 2005 and repeatedly in a year interval since 2014. For detail analyses, inside each permanent plot three 1x1m permanent quadrats were positioned. In each quadrat, in dm^2 frequency grid frame, vascular plants were counted and cover of moss species was estimated as precisely as possible on a percentage scale. The corners are indicated by white plastic pegs and fixed by GPS, geographical coordinates were recorded using the WGS 84 system, GPS GARMIN DACOTA 20. Investigation on the areas of $1m^2$ have been prefered by more researchers, e. g. FELDMEYER-CHRISTE et al. (2011) or REES & JUDAY (2002).

Location of permanent plots and permanent quadrats:

(REF) Reference stand, „Smrekovec" near Vyšné Hágy, 20 x 20 m. Unfortunately, in May 2014 the site was hit by another windstorm and was completely destructed.
Permanent quadrat 1, x 20°06.2417'; y 49°07.2919' REF 1
Permanent quadrat 2, x 20°06.2299'; y 49°07.2927' REF 2
Permanent quadrat 3, x 20°06.2232'; y 49°07.2949' REF 3

(EXT) Windthrow removed, location „Danielov dom", 20 x 20 m.
Permanent quadrat 1, x 20°09.7729'; y 49°07.2791' EXT 1
Permanent quadrat 2, x 20°09.7714'; y 49°07.2798' EXT 2
Permanent quadrat 3, x 20°09.7767'; y 49°07.2886' EXT 3

(NEX) Windthrow on forest floor, location „Jamy", 20 x 20 m.
Permanent quadrat 1, x 20°15.2002'; y 49°09.5749' NEX 1
Permanent quadrat 2, x 20°15.1902'; y 49°09.5736' NEX 2
Permanent quadrat 3, x 20°15.1857'; y 49°09.5729' NEX 3

(FIR) Fallen wood burnt, near Tatranské Zruby, 20 x 20 m.
Permanent quadrat 1, x 20°11.8069'; y 49°08.1970' FIR 1
Permanent quadrat 2, x 20°11.8047'; y 49°08.1984' FIR 2
Permanent quadrat 3, x 20°11.8005'; y 49°08.2029' FIR 3

Statistics

For statistical analysis we used ordinal frequency data without transformation. Multivariate exploratory technics of Statistical graphics system STATISTICA, Release 7, have been used. To determine the preference of selected species to the sites management, Factor analysis and for rotation of factors we used the varimax raw, that transforms the load factor so that the scattering of the squared was maximal. To identify the trajectories of post disturbance development, Canonical analysis have been used. The first set of variables consists of data related to reference site in the beginning of investigation in 2005, the floristic composition of the site kept relatively stability during investigation, untill wind destruction in 2014. The destruction caused disruption of continuity, further research on the site is impossible. The second set of variables includes data for rated sites in the relevant year.

Results and discussion

Data matrix for canonical analysis are in Tables 1, 2 and 3. Vascular plants are counted as stems, cover of bryophytes in cm^2.

Tab. 1. Data matrix for the Cannonical analysis, 2005. REF 2005 - reference site, FIR 2005, EXT 2005, NEX 2005 - rated sites.

	REF 2005			**FIR 2005**			**EXT 2005**			**NEX 2005**		
Quadrat	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Vacinium myrtillus	21	133	17	0	0	0	44	0	17	88	200	81
Oxalis acetosella	603	71	5	0	0	0	0	8	0	50	0	0
Avenella flexuosa	60	0	128	0	1	0	303	8	5	29	94	121
Melampyrum sylvaticum	0	10	4	0	0	0	0	0	0	0	0	0
Calamagrostis villosa	0	8	219	0	0	0	224	313	15	89	184	252
Vaccinium vitis-idaea	0	2	0	0	0	0	3	0	0	0	0	0
Luzula luzuloides	0	0	1	0	0	0	1	0	0	0	0	5
Homogyne alpina	0	0	10	0	0	0	0	0	0	0	0	0
Maianthemum bifolium	0	0	8	0	0	0	0	0	0	4	45	49
Calamagrostis arundinacea	0	0	0	0	0	0	1	0	0	0	0	0
Carex ovalis	0	0	0	0	0	0	1	0	0	0	0	0
Luzula sylvatica	0	0	0	0	0	0	6	0	0	0	0	0
Picea abies	0	0	0	0	0	0	0	0	0	1	0	16
Plagiomnium affine	25	0	0	0	0	0	0	0	0	0	0	0
Dicranum scoparium	270	1547	600	0	0	0	0	0	0	10	5	1352
Pleurozium schreberi	623	5	0	0	0	0	1100	0	0	32	0	320
Hylocomium splendens	0	280	220	0	0	0	3	6	0	115	1915	0
Ptilium crista-castrensis	0	96	1573	0	0	0	0	0	0	0	0	0
Polytrichum alpinum	0	0	10	0	0	0	0	0	0	0	0	0

Tab. 2. Data matrix for the Cannonical analysis, 2008. REF 2005 - reference site, FIR 2008, EXT 2008, NEX 2008 - rated sites.

	REF 2005			FIR 2008			EXT 2008			NEX 2008		
Quadrat	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Vacinium myrtillus	21	133	17	9	19	0	108	84	121	73	270	182
Oxalis acetosella	603	71	5	0	0	0	0	6	0	3	0	9
Avenella flexuosa	60	0	128	7	0	0	1695	1068	451	20	262	547
Melampyrum sylvaticum	0	10	4	0	0	0	0	6	0	0	0	0
Calamagrostis villosa	0	8	219	549	1458	30	485	2024	1317	1653	1279	844
Vaccinium vitis-idaea	0	2	0	0	0	0	44	5	0	0	0	0
Luzula luzuloides	0	0	1	0	8	0	198	0	0	0	0	10
Homogyne alpina	0	0	10	0	0	0	0	0	0	0	0	0
Maianthemum bifolium	0	0	8	0	0	0	0	0	0	42	41	245
Calamagrostis arundinacea	0	0	0	0	0	0	6	0	0	0	0	0
Carex ovalis	0	0	0	0	1	1	1	0	18	0	0	0
Luzula sylvatica	0	0	0	0	0	0	0	0	0	0	0	0
Picea abies	0	0	0	0	2	0	0	0	0	1	0	0
Veronica officinalis	0	0	0	2	68	68	0	0	0	1	0	0
Chamaerion angustifolium	0	0	0	3	145	120	0	0	7	0	0	0
Rubus idaeus	0	0	0	1	3	2	0	0	0	0	0	0
Viola riviniana	0	0	0	1	1	1	0	0	0	0	0	0
Calluna vulgaris	0	0	0	0	30	0	8	0	0	0	0	0
Hypericum maculatum	0	0	0	0	4	0	0	0	0	0	0	0
Salix caprea	0	0	0	0	1	0	0	0	0	0	0	0
Senecio nemorensis	0	0	0	0	0	1	0	0	0	0	0	0
Rhytidiadelphus squarrosus	0	0	0	0	0	0	0	0	0	20	15	0
Plagiomnium affine	25	0	0	0	0	0	0	1	0	0	0	0
Dicranum scoparium	270	1547	600	0	0	0	0	1	0	37	15	1105
Pleurozium schreberi	623	5	0	0	0	0	0	0	0	3	25	750
Hylocomium splendens	0	280	220	0	0	0	0	0	0	5	5	0
Ptilium crista-castrensis	0	96	1573	0	0	0	0	0	0	0	0	0
Polytrichum alpinum	0	0	10	0	0	0	0	0	0	0	0	0
Polytrichum formosum	0	0	0	0	65	0	0	0	0	0	0	0

Tab. 3. Data matrix for the Cannonical analysis, 2013. REF 2005 - reference site, FIR 2013, EXT 2013, NEX 2013 - rated sites

	REF 2005			FIR 2013			EXT 2013			NEX 2013		
Quadrat	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Vacinium myrtillus	21	133	17	63	51	0	130	86	27	5	81	86
Oxalis acetosella	603	71	5	0	0	0	0	0	0	1	1	15
Avenella flexuosa	60	0	128	176	10	15	952	1102	1387	14	375	324
Melampyrum sylvaticum	0	10	4	0	0	0	0	0	0	0	0	0
Calamagrostis villosa	0	8	219	1303	1103	2077	293	670	1369	1119	1585	1208
Vaccinium vitis-idaea	0	2	0	0	0	0	351	78	0	0	0	0
Luzula luzuloides	0	0	1	11	53	6	120	0	8	0	0	4
Homogyne alpina	0	0	10	0	0	0	0	0	0	0	0	0
Maianthemum bifolium	0	0	8	7	0	13	0	0	0	8	15	26

Tab. 3. – cont.

	REF 2005			FIR 2013			EXT 2013			NEX 2013		
Quadrat	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Calamagrostis arundinacea	0	0	0	0	0	0	5	0	0	0	0	5
Carex ovalis	0	0	0	0	0	0	0	0	0	0	0	0
Luzula sylvatica	0	0	0	13	0	0	0	0	0	0	0	0
Picea abies	0	0	0	0	0	0	0	0	0	1	0	0
Veronica officinalis	0	0	0	21	74	5	0	0	0	0	0	0
Chamaerion angustifolium	0	0	0	9	4	47	5	9	65	14	30	29
Rubus idaeus	0	0	0	4	1	18	0	6	3	7	8	26
Viola riviniana	0	0	0	1	0	1	0	0	0	0	0	0
Calluna vulgaris	0	0	0	0	242	0	29	0	0	0	0	0
Hypericum maculatum	0	0	0	0	7	0	0	0	0	0	0	0
Carex pilulifera	0	0	0	53	0	15	0	57	0	0	0	0
Larix decidua	0	0	0	0	1	0	0	0	0	0	0	0
Luzula luzulina	0	0	0	0	5	0	0	0	0	0	0	0
Sorbus aucuparia	0	0	0	0	0	0	0	1	0	0	0	0
Plagiomnium affine	25	0	0	0	0	0	0	30	0	0	0	0
Dicranum scoparium	270	1547	600	0	0	0	0	0	0	30	60	110
Pleurozium schreberi	623	5	0	0	0	0	130	0	0	5	40	100
Hylocomium splendens	0	280	220	0	0	0	0	0	0	10	0	0
Ptilium crista-castrensis	0	96	1573	0	0	0	0	0	0	0	0	0
Polytrichum alpinum	0	0	10	0	0	0	0	0	0	0	0	0

To interpret the trajectories, we superimposed the presence of two species with wellknown ecological response, *Calamagrostis villosa* and *Chamaerion angustifolium*. Relatively heliophilous grass *Calamagrostis villosa* dominates the understory of spruce forests, but especialy clearings and felled areas. *Chamaerion angustifolium* is a typical pioneer species, which also temporarily benifits from disturbance.

Calamagrostis villosa

The numbers of stems of *Calamagrostis villosa* counted on permanent quadrats in sites REF, EXT, FIRE and NEX are shown in Tab. 4.

Tab. 4. Data matrix, *Calamagrostis villosa*. Number of stems in permanent quadrats in 2005-2013.

	REF			EXT			FIR			NEX		
Quadrat	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
2005	0	8	219	224	313	15	11	21	0	89	184	252
2006	0	12	209	225	1227	811	495	736	0	541	1029	451
2007	0	12	163	233	1346	1333	831	1635	0	864	1309	583
2008	0	10	135	485	2024	1317	549	1458	30	1653	1279	844
2009	0	23	118	485	419	1926	1422	1817	182	1344	2526	1182
2010	0	14	85	1483	1901	1960	2318	1287	494	1325	1691	1366
2011	0	27	82	439	1718	2315	2411	1321	1117	1554	2460	1247
2012	0	30	84	272	1261	1343	1755	1103	1605	1332	1820	1421
2013	20	70	80	293	670	1364	1303	1103	2077	1119	1585	1208

Tab. 5. Factor analysis results, *Calamagrostis villosa*

Variable		Factor 1	Factor 2	Factor 3	Factor 4
REF	Quadrat 1	-0,082466	*0,917503	-0,128943	-0,054128
	Quadrat 2	0,204560	*0,959295	-0,026638	-0,153465
	Quadrat 3	-0,674359	-0,537880	-0,434894	-0,204143
EXT	Quadrat 1	0,165090	-0,171266	*0,824519	0,311627
	Quadrat 2	0,245846	-0,198879	0,232228	*0,895031
	Quadrat 3	*0,889450	0,086537	0,340368	0,195956
FIR	Quadrat 1	0,659245	0,235020	0,663913	0,088025
	Quadrat 2	*0,902877	-0,066453	-0,112626	0,231901
	Quadrat 3	0,215645	*0,909709	0,212990	-0,027121
NEX	Quadrat 1	*0,812295	0,171674	0,159936	0,467072
	Quadrat 2	*0,951825	0,146263	0,209501	-0,075981
	Quadrat 3	0,693237	0,436936	0,516704	0,106470

*Indicates significancy

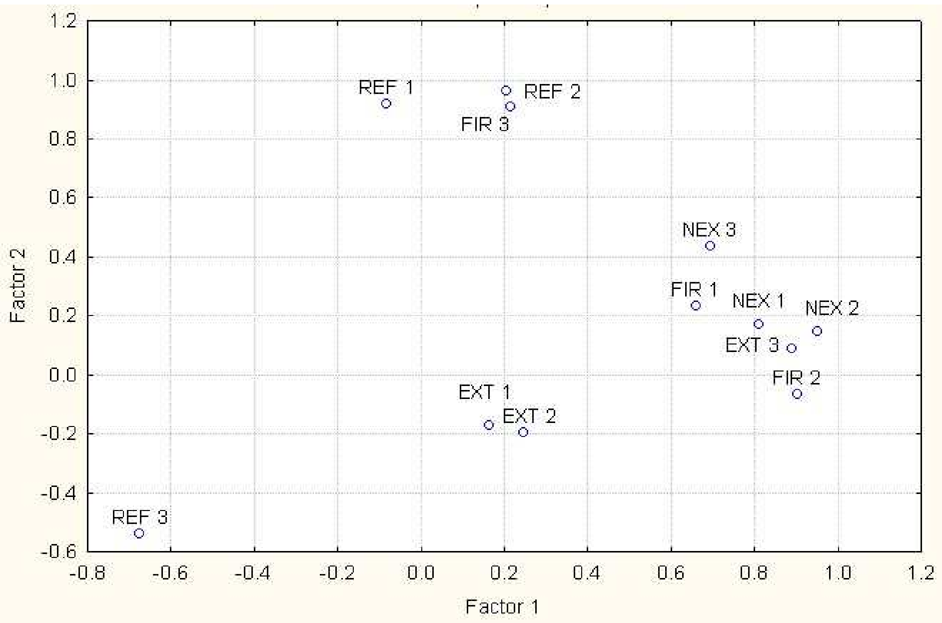

Fig. 1. Factor loadings, *Calamagrostis villosa*, Factor 1 vs. Factor 2, Rotation: Varimax raw, Extraction: Principal components.

The factor loadings of *Calamagrostis villosa* are presented in Tab. 5. Four factors explained 93,1% of variance. Factor results suggest that Factor 1 indicates (a) permanently developed herb layer, (b) survived living underground part on the site FIR, (c) rapid increase of cover of *Calamagrostis villosa* in 2006-2008 in sites EXT 3, FIR 2 and NEX 1,2. These sites create an isolated group right hand of Fig. 1. Factor 2 indicates lower cover of *Calamagrostis villosa* in sites REF 1, 2 in spruce forests near climax stage in 2005-2008 and shift in the pH level to acidic areas. Similar progress of *Calamagrostis villos*a is seen on the site FIR 3, but the total absence of vegetation in 2005 and much reduced vegetation in 2006-2007 is a feature of primary succession (FELDMEYER-CHRISTE et al. 2011), the development is specific by a massive expansion of *Calamagrostis villosa* in 2011-2013. The sites are seen as isolated group up of Fig. 1.

Factor 3 and Factor 4 indicated a strong development of *Calamagrostis villosa* in 2010 (2008 respectively) and consecutively dropped on sites with windthrow removal (EXT 1 and EXT 2). The sites are seen on Fig. 1.

Calamagrostis villosa recorded maximum development in a favourable light conditions on the EXT or NEX sites in the period from 2008 to 2011, i. e. 4 to 7 years after the destruction event. The massive development of *Calamagrostis villosa* causes a reduced germination of seeds and for this reason the grass retreated in cover.

Chamaerion angustifolium

Tab. 6. Data matrix, *Chamaerion angustifolium*. Number of stems in permanent quadrats in 2005-2013.

	REF			EXT			FIR			NEX		
Quadrat	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
2005	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	1	2	0	0	0
2007	0	0	0	0	0	0	0	2	119	0	0	0
2008	0	0	0	0	0	7	3	145	120	0	0	0
2009	0	0	0	0	0	10	18	7	79	7	7	7
2010	0	0	0	0	0	2	10	4	60	3	1	1
2011	0	0	0	0	0	25	18	9	49	4	8	4
2012	0	0	0	0	0	13	8	4	35	11	4	7
2013	0	0	0	5	9	65	9	4	47	14	30	29

Tab. 7. Factor analysis results, *Chamaerion angustifolium*.

Variable		Factor 1	Factor 2	Factor 3	Factor 4
	Quadrat 1	*0.991981	0.020550	-0.062957	0.042758
EXT	Quadrat 2	*0.991981	0.020550	-0.062957	0.042758
	Quadrat 3	*0.945432	0.042455	0.263395	-0.030616
	Quadrat 1	0.130580	-0.067479	*0.969436	0.079374
FIR	Quadrat 2	-0.081776	-0.303223	-0.099461	*-0.942747
	Quadrat 3	-0.045981	*-0.954192	0.058741	-0.288122
	Quadrat 1	*0.745231	0.090834	0.491611	0.176620
NEX	Quadrat 2	*0.958847	0.028506	0.245147	0.084512
	Quadrat 3	*0.968611	0.036213	0.204607	0.099520

*Indicates significancy

The factor loadings of *Chamaerion angustifolium* are presented in Tab. 7. Four factors explained 96,7% of variance. Factor 1 indicates areas without *Chamaerion angustifolium* until 2008, explained 62 % of variance and was related to site EXT 1, 2, 3 and NEXT 1, 2, 3. These areas form an isolated group standing oposite the FIR sites (Fig. 2). Factor 2, 3 and 4 apply to site FIR 1, 2 and 3. The colonisation of the site FIR has features of primary succession (FELDMEYER-CHRISTE et al. 2011).

Chamaerion angustifolium recorded the maximum development in the sites affected by the fire (FIR), in connection with the higher nitrogen stocks in the years 2007-2008. In the next succession, proportionaly with the reduction of nitrogen supply, the occurence of *Chamaerion angustifolium* was decreasing (Tab. 6).

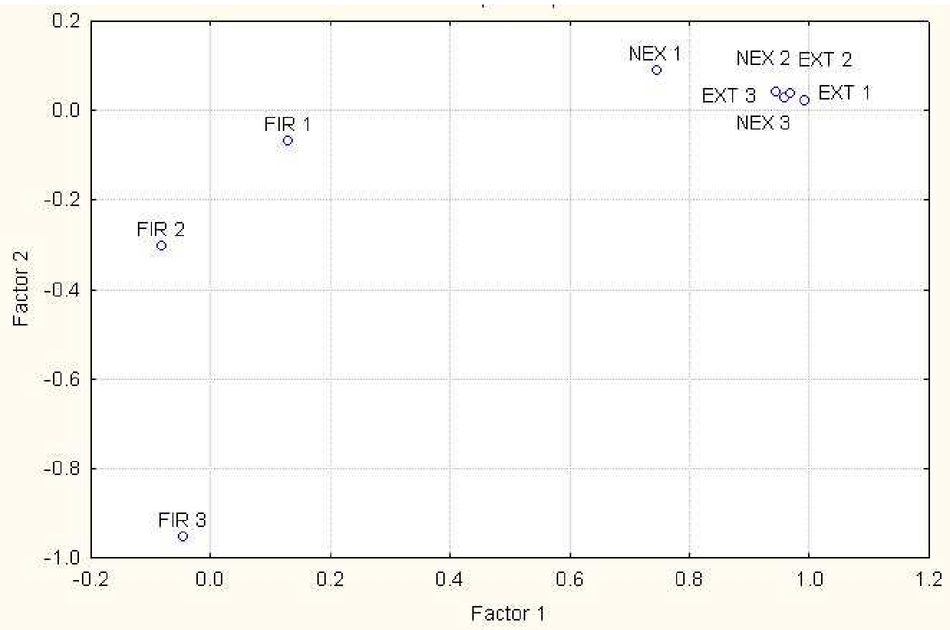

Fig. 2. Factor loadings, *Chamaerion angustifolium*, Factor 1 vs. Factor 2, Rotation: Varimax raw, Extraction: Principal components.

Post disturbance successional trajectories

The hypothesis of convergence in vegetation succession is based on the „climax" theory, according to which all successional series in an area with the same climate will eventually converge towards a unique final community (FELDMEYER-CHRISTE et al. 2011).

Canonical „R" related to the REF site suggest the direction of the post disturbance development (Tab. 8).

Tab. 8. Results of Canonical analysis, canonical „R“ values related to the REF site.

		FIR	EXT	NEX
2005	Canonical „R“ value	*	0,6917	0,9605
	Chi-Square	*	9,0973	31,3042
2008	Canonical „R“ value	0,1968	0,2522	0,8565
	Chi-Square	1,0934	1,2623	18,0059
2013	Canonical „R“ value	0,1779	0,2469	0,8435
	Chi-Square	0,9081	1,4249	18,1163

* Ill conditioned, too much zero values

Canonical „R“ of NEX site in 2005 near 1 (0,9605) suggests, that the differences in understory vegetation between NEX site and reference site are minimal. Canonical „R“ value of NEX site in 2005 – 2013 decreased only moderately (Tab. 8). The explanation is simple, the understory vegetation is protected by windthrow left on forest floor. The trend is different if the windthrow was removed (EXT) or hit by fire (FIR), especially in relation to the nitrogen. On the site without treatment (NEX), we haven´t recorded the development of nitrophilous vegetation, in particular, we have seen the development of heliophilous vegetation, this trend indicates *Calamagrostis villosa* and *Avenella flexuosa.* In the course of time, the felled-area species like *Calamagrostis villosa, Vaccinium myrtillus, Rubus idaeus* and *Chamaerion angustifolium* penetrate only slowly the floristical composition. Immediately after the canopy fell down, the moss species *Dicranum scoparium* and *Hylocomium splendens* partly retreated, but since 2008 they regenerated in almost original dominance. To this site, preferentially is fixed *Maianthemum bifolium* and *Oxalis acetosella* (Tab. 3).

The developmental trajectory looks quite different in the case of where windthrow has been removed, EXT site. Already in the first year after the event, the moss layer suffered a sharp reduction. All the circumstances are reflected in a rapid decrease in canonical „R“ in 2005 – 2008 (0,6917-0,2522), during 2008 – 2013 the canonical „R“ value remained relatively stable (0,2522-0,2469) (Tab. 8). Immediately after the wind disaster, the vegetation kept the structure of the understory of the forest ecosystem. Soon we have recorded the massive development of heliophilous species like *Avenella flexuosa, Calamagrostis villosa, Vaccinium vitis-idaea, Vaccinium myrtillus***,** the species dominate the site till today. Since 2007, heliophilous grass *Calamagrostis arundinacea* entered the floristical composition, the species shows a higher affinity to nitrogen compared to relative species *Calamagrostis villosa*, and also *Chamaerion angustifolium,* which indicates higher supply of nitrogen in the soil as well. Chamaephytes appear less frequently. To this site, preferentially is fixed *Avenella flexuosa* and *Vaccinium vitis-idaea* (Tab. 3).

A specific case is the FIR site. In 2005, the correlation matrix was ill conditioned (too many zero values) and couldn´t be inverted. In 2008, canonical "R" was 0,1968. In 2013, we expected an increased "R" value in accordance with the anticipated convergence to the felled area composition. Decrease of the cannonical R (0,1779) is unexpected. But LEPŠ & REJMÁNEK (1991) maintain that the temporal divergence does not necessarily rule out eventual convergence. In 2005, the plot had a patchy mosaic with heavily charred large patches and less burnt patches with sporadic occurence of *Calamagrostis villosa,* indicating that root systems survived the fire, and within two years *Calamagrostis villosa* locally dominated the site. Soon after the fire event the moss layer disappeared. The quadrats were selected in aim to cover the whole ecological niche. Quite different succession took place in places where fire had burned root systems of *Calamagrostis villosa* and areas were locally without vegetation even in 2006, these areas were occupied by Rosebay Willow-herb (*Chamaerion angustifolium)*. Four years after the fire, the plot was dominated by the nitrophilous felled-area species *Chamaerion angustifolium* and development of *Calamagrostis villosa* was also recorded. Some weed species entered the floristical composition, e. g. *Galeopsis tetrahit, Trifolium repens, Senecio sylvaticus, Urtica dioica,* and the shrub *Sambucus racemosa*, all of which favor high nitrogen availability. From 2008, the cover of the *Chamaerion angustifolium* decreased gradually in line with the falling stocks of nitrogen in the soil and the cover of *Calamagrostis villosa* was rising. To this site, preferentially is fixed *Luzula luzuloides* and *Viola riviniana* (Tab. 3).

Conclusion

The use of canonical analysis and factor analysis for identification of successional trajectories proved to be a suitable technique. We explored vegetation trajectories of FIR, NEX or EXT sites refered to REF site. Based on canonical analysis and factor analysis, our results show that in the Tatra Mts during the early succession in 2004-2013, we indeed observe divergent successional trajectories after the disturbance. In the case of NEX and EXT sites, the first phase of rapid compositional changes culminated in 2008 and was followed by a deceleration phase, continuing to 2013. In the further development, we expect to see a turnaround and the start of convergent succession towards forest ecosystem. When this will occur, we do not know, but we will continue monitoring. An entirely different trajectory is seen on the FIR site, because the colonization process on completely charred soil on the FIR site has features of primary succession, since vegetation development is growing on new substrate that contains no biological legacy (FELDMEYER-CHRISTE et al. 2011).

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References

BEVILAQUA D. (2000): Je El Niňo zodpovedný za požiar v Slovenskom raji?. – Enviromagazin 5(6): 10-11.

BUDZÁKOVÁ M., GALVÁNEK D., LITTERA P. & ŠIBÍK J. (2013): The wind and fire disturbance in Central European mountain spruce forests: the regeneration after four years. – Acta Societatis Botanicorum Poloniae 82(1): 13-24.

FAJMONOVÁ E. (1975): Fytocenologický materiál k rúbaniskovým spoločenstvám vo flyšovom pásme Západných Karpát. – Biológia 30: 743-755.

FELDMEYER-CHRISTE E., KÜCHLER M. & WILDI O. (2011): Patterns of early succession on bare peat in a Swiss mire after a bog burst. – Journal of Vegetation Science 22(5): 943-954.

FRANKLIN J. F. & SPIES T. A. (1991): Composition, function, and structure of old-growth Douglas-fir forests. – In: RUGGIERO L.F., AUBRY K.B., CAREY A.B., & HUFF M.H. (eds.): Wildlife and vegetation of unmanaged Douglas-fir forests, technical coordination. General Technical Report PNW-GTR-285. Portland, OR: U.S. Forest Service, Pacific Northwest Research Station, p. 71-80.

HOLECY J., TUČEK J., ŠKVARENINA J. & MINĎAŠ J. (2004): Výskyt lesných požiarov v Národnom parku Slovenský raj, výsledky štatistickej analýzy. – In: DIVOK F. (ed.): Zborník referátov k 40. výročiu ochrany prirody v Národnom parku Slovenský raj, Zvolen, p. 76-85.

HOMOLOVÁ Z., KYSELOVÁ Z. ŠOLTÉS R. & ŠKOLEK J. (2009): Changes of vegetation on the calamity area since 2005. – In: HOMOLOVÁ Z. & FLEISCHER P. (eds.): Pokalamitný výskum v TANAPe 2009. Zborník prezentácií zo IV. Seminára, CD, ISBN 978-80-970332-0-0.

HOMOLOVÁ Z., KYSELOVÁ Z., ŠOLTÉS R. & ŠKOLEK J. (2011): Iniciálne štádiá sukcesie na kalamitných plochách s rôznym typom manažovania v Tatranskom národnom parku. – Štúdie TANAP 10(43): 145-155.

CHOVANCOVÁ-OLŠAVSKÁ G. & KRIŽOVÁ E. (2009): Secondary succesion of vegetation on the permanent monitoring plots in the High Tatras Mts. – In: PRIBULLOVÁ A. & BIČÁROVÁ S. (eds.): Sustainable development and bioclimate, Proceeding, Stará Lesná, p. 115-116.

JANČOVÁ M. (1993): Prirodzená obnova lesného spoločenstva požiarom poškodenej časti ŠPR "Kyseľ" v národnom parku Slovenský raj 1994. – In: BALÁŽ D. (ed): Zborník referátov zo seminára v Záhorskej Bystrici 6–8 apríl 1993, p. 73-79.

JANČOVÁ M. (2006): Prirodzená obnova lesa na plochách poškodených požiarom na priklade Národnej prírodnej rezervácie Kyseľ. Technická univerzita vo Zvolene, 66 pp.

JANE G. T. & GREEN T. G. A. (1986): Etiology of forest dieback area within the Kaimai Range, North Island, New Zealand. – New Zealand Journal of Botany 24**:** 513-527.

KRIŽOVÁ E. (1994): Odraz zmenených ekologických podmienok v zložení a produkcii lesných fytocenóz ŠPR "Pod Latiborskou hoľou". – Acta Facultatis Forestalis 36: 63-73.

KRIŽOVÁ E., CHOVANCOVÁ G. & HOMOLOVÁ Z. (2011): Produkcia biomasy a konkurenčné vzťahy vybraných druhov na monitorovaných plochách vo Vysokých Tatrách. – Štúdie TANAP 10(43): 157-169.

KUBINSKÁ A. & JANOVICOVÁ K. (1998): Bryophytes. – In: MARHOLD K. & HINDÁK F. (eds.): Checklist of non-vascular and vascular plants of Slovakia. Veda, Bratislava, p. 297-332.

LEPŠ J. & REJMÁNEK M. (1991): Convergence or divergence, what should we expect from vegetation succession? – Oikos 62: 261-264.

LESKOVJANSKÁ A. (1995): Sukcesia v požiarom postihnutej oblasti NPR Kyseľ v Národnom parku Slovenský raj. – In: KRIŽOVÁ, E. & UJHÁZY, K. (eds): Zborník referátov zo seminára ANCY „Sekundárna sukcesia", Technická univerzita Zvolen, p. 33-42.

MARHOLD K. (1998): Ferns and flowering plants. – In: MARHOLD K. & HINDÁK F. (eds.): Checklist of non-vascular and vascular plants of Slovakia. Veda, Bratislava, p. 333-687.

MARTIN J. & GOWER T. (1996): Forest Succession. – Forestry Facts 78: 1-4.

MILLER E. A. & HALPERN C. B. (1998): Effects of environment and grazing disturbance on tree establishment in meadows of the central Cascade Range, Oregon, USA. – Journal of Vegetation Science 9: 265-282.

NOVOTNÝ J. (1998): Keď les vstáva z popola. – Les 54: 1-2.

OLŠAVSKÁ G., KRIŽOVÁ E. & ŠOLTÉS R. (2008): Pokalamitný vývoj vegetácie na trvalých monitorovacích plochách vo Vysokých Tatrách. – In: FLEISCHER P. & MATEJKA F. (eds.): Pokalamitný výskum v TANAPe 2008. Zborník príspevkov, CD, ISBN 978-80-85754-20-9.

PICKETT S. T. A., MEINERS S. J. & CADANASSO M.L. (2011): Domain and Propositions of Succession. – In: SCHEINER S. M. & WILLIG M. R. (eds): The Theory of Ecology. The University of Chigago Press, p. 185-218.

REES D. C. & JUDAY G. P. (2002): Plant species diversity on logged versus burned sites in Central Alaska. – Forest Ecology and Management 155: 291-302

ŠOLTÉS R., CHOVANCOVÁ B., ŠKOLEK J., HLÔŠKA L., ŠOLTÉSOVÁ A., HOMOLOVÁ Z. & KORNAJČÍK, M. (2007a): Monitoring bioty na kalamitných hydrologicky manažovaných plochách. – In: FLEISCHER P. & MATEJKA F. (eds): Pokalamitný výskum v TANAPe 2007. Zborník príspevkov, CD, ISBN 978-80-85754-17-9.

ŠOLTÉS R., ŠKOLEK J., HOMOLOVÁ Z. & KYSELOVÁ Z. (2007b): Sekundárna sukcesia na kalamitných plochách vo Vysokých Tatrách v rokoch 2005-2007. – In: FLEISCHER P. & MATEJKA F. (eds): Pokalamitný výskum v TANAPe 2007. Zborník príspevkov, CD, ISBN 978-80-85754-17-9.

ŠOLTÉS R. ŠKOLEK J. & KYSELOVÁ Z. (2008): Pokalamitný vývoj vegetácie. – In: FLEISCHER P. & MATEJKA F. (eds): Pokalamitný výskum v TANAPe 2008. Zborník príspevkov, CD, ISBN 978-80-85754-20-9.

ŠOLTÉS R., ŠKOLEK J., HOMOLOVÁ Z. & KYSELOVÁ Z. (2010): Early successional pathways in The Tatra Mountains (Slovakia) forest ecosystems following natural disturbances. – Biologia, 65(5): 958-964.

UJHÁZY K. (2003): Sekundárna sukcesia na opustených lúkach a pasienkoch Poľany. Technická univerzita vo Zvolene, 104 pp.

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